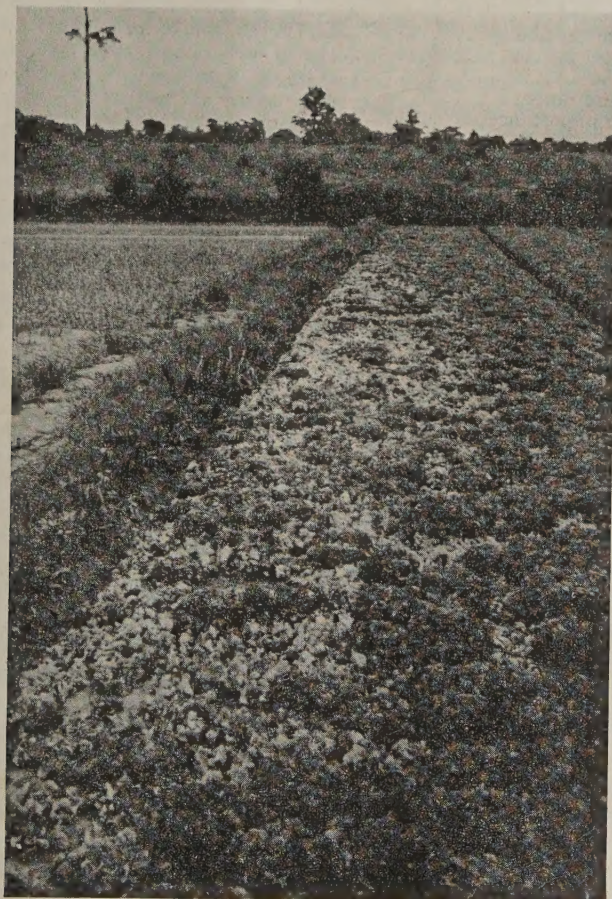




The Yellows Disease of Lettuce and Endive

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THE YELLOWS DISEASE OF LETTUCE AND ENDIVE¹

M. B. LINN

The aster-yellows virus, the cause of lettuce and endive yellows, was shown by Kunkel in 1924 to be transmitted by the leafhopper *Macrostes divinus* (Uhl.). Since then, numerous contributions have been made to the knowledge of the susceptible range of the virus; of the effect of heat on the virus in the vector; and of control by screening, by roguing, and by dusting with insecticides. However, little is yet known about dissemination of the vector and the virus in relation to control of the disease.

During the years 1935 to 1939, the writer conducted an investigation into the yellows disease in lettuce and endive, a limiting factor in the production of late-summer and fall crops. It is believed that the results of this study provide a basis for practical control measures for the disease on these two susceptibles.

The experimental work was done in the greenhouses and on the farms of 25 members of the Staten Island Growers' Association, Inc., Staten Island, New York, to which section of the State the results apply in particular.

SUSCEPTS

PLANTS AFFECTED

Kunkel (1926, 1931) transmitted the Eastern aster-yellows virus with *Macrostes divinus* (Uhl.) (*Cicadula sexnotata* Fall.) to 170 species of plants in 150 genera belonging to 38 families. He was unsuccessful in attempts to transmit the virus to tobacco (*Nicotiana tabacum* L.), celery (*Apium graveolens* L.), zinnia (*Zinnia elegans* Jacq.), and potato (*Solanum tuberosum* L.). Transmission to tomato was obtained only by grafting onto it buds of *Nicotiana rustica* L. affected with the disease.

Severin (1934b) reports successful transmission of the California form of the yellows virus with *Macrostes divinus* to celery and *Zinnia elegans*; with *Thamnotettix montanus* Van Duz. to aster, celery, carrot, White London mustard (*Brassica alba* (L.) Boiss.), Prickly Winter spinach, Prize-head lettuce, and plantain; and with *Thamnotettix geminatus* Van Duz. from experimentally and naturally inoculated celery to healthy celery. Severin and Haasis (1934) were able to transmit the yellows virus to potato by *Macrostes divinus*, although the virus was not subsequently recovered from the experimentally inoculated potato plants or tubers.

According to Severin (1934a), the overlapping economic susceptibles of the Eastern and California forms of yellows are: buckwheat (*Fagopyrum esculentum* Moench.), spinach (*Spinacea oleracea* L.), carrot (*Daucus carota* L.), dill (*Anethum graveolens* L.), parsnip (*Pastinaca sativa* L.), peas-

¹Also presented to the Faculty of the Graduate School of Cornell University, June, 1940, as a thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENTS. The writer wishes to thank Dr. A. G. Newhall and Dr. G. F. MacLeod for suggestions and encouragement during the progress of this investigation.

Thanks are also due Dr. V. L. Frampton for help in arranging certain of the data and W. R. Fisher for the photographs of the charts.

Appreciation is expressed also to the Staten Island Growers' Association under the terms of whose fellowship this work was made possible.

ant's tobacco (*Nicotiana rustica*), salsify (*Tragopogon porrifolius* L.), and lettuce (*Lactuca sativa* L.).

On the basis of the work of Kunkel and Severin, there appear to exist two distinct strains of the virus, which may be distinguished by the difference in their suscept range. Smith (1933) is of the opinion that slight differences in suscept range do not justify the separation into distinct viruses of entities which are otherwise identical.

Leach (1939) reports experiments which indicate that a disease of potato, "purple-top wilt", recorded from Minnesota and West Virginia, may be caused by the aster-yellows virus. Whether this disease is caused by the Eastern or California strain of the virus has not as yet been determined.

According to McMillen (1928), Chupp reported in 1927 the occurrence on Long Island of a disease of escarole (broad-leaf endive) resembling lettuce yellows. A yellows disease of the two varieties of endive (*Cichorium endivia* L.—curled-leaf, and escarole) commonly grown on Staten Island was first observed by the writer during 1933. Correspondence² with Dr. L. O. Kunkel revealed that endive had not yet been reported as a suspect of the aster-yellows virus. The following experiments were therefore conducted to ascertain whether this virus causes endive yellows.

Yellowed curled-leaf endive and escarole plants were brought into the greenhouse from the field and, after an isolation period to insure freedom from insects, were infested with non-viruliferous *M. divisus*³ (figure 1). At the end of five days some of these leafhoppers were placed on young healthy aster and lettuce plants. All of these plants showed symptoms of

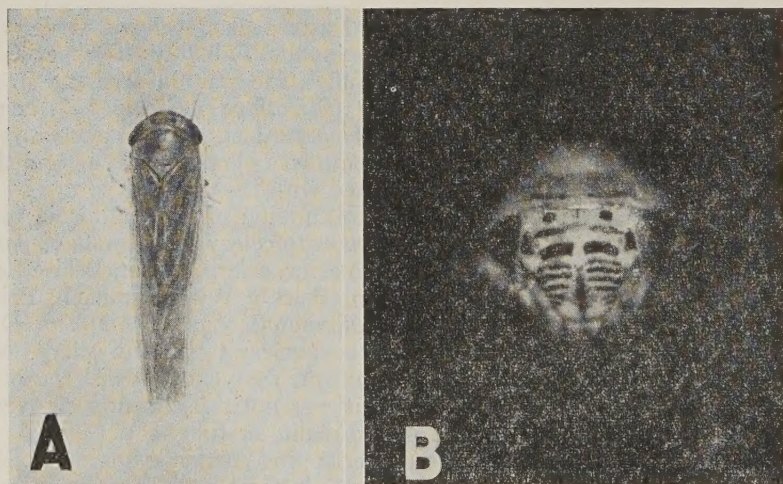


FIGURE 1. A, ADULT MACROSTELLES DIVISUS, LEAFHOPPER VECTOR OF YELLOWS VIRUS IN LETTUCE AND ENDIVE

B, HEAD OF ADULT *M. DIVISUS* SHOWING SIX SPOTS ON THE VERTEX (AN ADDITIONAL TRIANGULAR SPOT ON THE MARGIN OF EACH EYE) AND TWO SERIES OF ARCS ON THE FRONT. The arrangement of these markings appears to be fairly constant on those specimens collected on Staten Island

²Letter dated November 21, 1933.

³Specimens of *M. divisus* were sent to Dr. D. M. DeLong of Ohio State University for identification. No other vector of the yellows virus has been found on Staten Island.

yellows after sixteen days. Following the fumigation of these plants to kill the vector, non-viruliferous leafhoppers (*M. divisus*) were placed on them; five days later these were transferred to healthy escarole and curled-leaf-endive seedlings. Fifteen days after infestation with the vector, these plants developed symptoms of yellows similar to those found on field-inoculated plants (figures 6 and 7).

In another experiment the virus was transmitted by the vector from field-inoculated lettuce plants to healthy curled-leaf-endive and escarole plants, with the same results. Attempts to transmit the lettuce- and endive-yellows virus to celery (Golden self-blanching) and to *Zinnia elegans* by means of viruliferous leafhoppers were unsuccessful. The results of these experiments thus give positive evidence that the yellows disease of endive is caused by the Eastern aster- (or lettuce-) yellows virus, and they indicate again the separate identity of the Eastern and California strains of the virus.

VARIETAL SUSCEPTIBILITY

Severin (1929) found that the following varieties of lettuce are susceptible to the California aster-yellows virus: Big Boston, Chicken, Early Curled Simpson, New York, Prizehead, Paris White Cos (Romaine), and Wonderful.

Observations made by the writer on the amount of yellows in Big Boston, Iceberg No. 12, and Romaine growing on the same bed indicate that Big Boston may be slightly less susceptible to the disease than are the other two varieties. On the other hand, unpublished reports from other workers indicate that certain strains of Iceberg may be less susceptible than Big Boston or Romaine. The question arises as to whether these differences are due

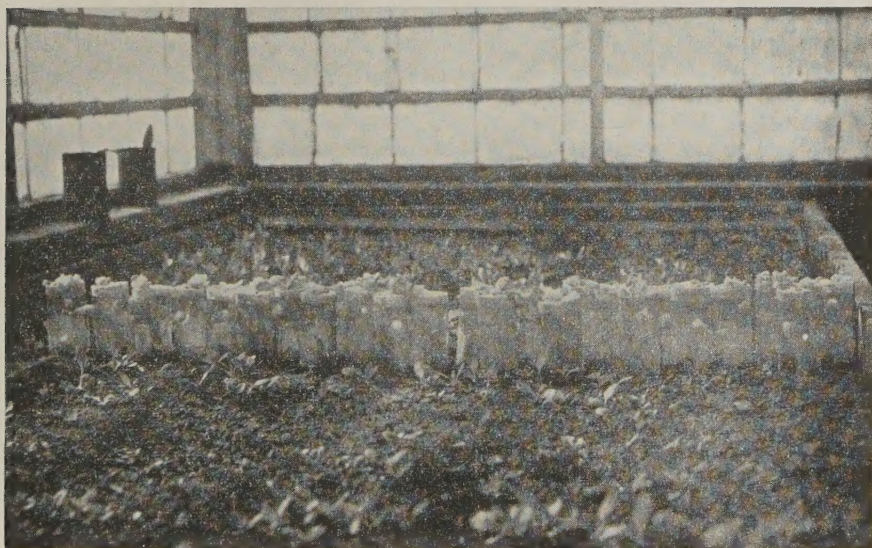


FIGURE 2. CAGES USED IN TESTING TWENTY-THREE VARIETIES AND STRAINS OF LETTUCE FOR SUSCEPTIBILITY TO THE YELLOWS VIRUS

to variations in susceptibility or to other factors. An experiment was performed to determine this point.

It is recognized that every plant in each variety tested for susceptibility should be exposed to feeding by the vector, a situation difficult to meet in a field experiment. Therefore small celluloid and cheesecloth cages were placed individually over each of 25 seedlings (2 inches tall) of 23 different varieties and strains of lettuce growing in greenhouse benches (figure 2). These varieties and strains are listed below. Four leafhoppers which had fed on yellowed lettuce plants for 10 days were placed in each cage. Five plants of each variety or strain were covered with individual unfested cages and left as checks. The leafhoppers were allowed to feed for 10 days, after which the individuals still alive in each cage were counted and then killed by fumigation. These counts showed that the leafhopper mortality rate ranged from 0 to 3 in each cage. The differences in mortality within and between varieties and strains were insignificant, thus indicating that all varieties and strains of lettuce in this test served equally well as host plants for the vector under caged conditions.

Varieties and Strains of Lettuce Tested and Found Susceptible to the Lettuce-Yellows Virus

1. Big Boston (Black-seeded)	13. Imperial 3
2. Big Boston (White-seeded)	14. Imperial 847
3. Brown Dutch	15. Mammoth Black-seeded Butter
4. California Cream Butter	16. May King
5. Crisp-as-Ice	17. Mignonette
6. Curly Continuity	18. Morse Regular
7. Drumhead (Malta)	19. Morse 41
8. Express Cos (Romaine)	20. Salamander
9. Green Paris Cos (Romaine)	21. Wayahead
10. Hubbard's Market	22. White Boston (White-seeded)
11. Imperial C	23. White Paris Cos (Romaine)
12. Imperial 2-50	

Symptoms of yellows began to appear on the caged seedlings 15 days after infestation. At the end of three weeks, every one of the 25 plants in each variety and strain in the experiment had developed symptoms of yellows.

The results of this experiment would suggest that variations in the incidence of yellows in commercial plantings of lettuce varieties are probably due to preferential feeding on the part of the vector and, therefore, are not criteria for determining either true varietal susceptibility or toxicity of the varieties to the vector.

THE DISEASE

NAMES

The disease on lettuce is known as the "Rio Grande disease", "white heart", "rabbit's ear", and "yellows". The first three names are seldom encountered in the current literature, having been superseded by the name "yellows", since the latter indicates the fact that the disease is caused by the aster-yellows virus.

The nomenclature with respect to yellows in endive is less involved in that "yellows" is the only name that has been applied to this disease in the literature.

HISTORY AND RANGE

Yellows in lettuce was first described by Carpenter (1916) who stated that it was particularly severe in the Rio Grande Valley in Texas. It was reported in 1918 as occurring in such widely separated areas as "the market gardens" near Chicago, and the New Orleans region of Louisiana.

The disease was first reported from New York State in 1921 by Dye (Coons, 1922). At that time it was observed in most of the principal lettuce-growing sections of the State. He states that the disease had been noted in previous seasons but was "not at all serious". The year of its appearance on Staten Island is largely a matter of conjecture, since no extensive disease surveys were made there prior to 1933. Conversations with growers long-established on Staten Island indicate that the disease probably appeared about the same time that it was found in upstate counties.

Lettuce yellows⁴ has been reported up to the present time from California, Connecticut, Delaware, Florida, Maine, Massachusetts, Minnesota, New Jersey, New York, Pennsylvania, Tennessee, Texas, Wisconsin (United States Plant Industry Bureau, *Plant Disease Reporter* and its supplements), and from Bermuda (Ogilvie, 1927) and Ontario (Caesar and Ross, 1933).

Endive yellows was first recorded in Nassau County, Long Island, New York, by Chupp in 1927. It was reported from New Jersey and again from Long Island in 1936. In both of the latter instances, entire fields were affected. The disease was first reported from Staten Island in 1933 but, as



FIGURE 3. LEFT, PLANT INFECTED WITH THE YELLOWS VIRUS; RIGHT, HEALTHY ROMAINE LETTUCE PLANT

⁴No attempt is made in this paper to separate the Eastern and California yellows on the basis of geographical range.

with lettuce yellows, indications are that the disease was present in previous seasons.

ECONOMIC IMPORTANCE

The average loss from lettuce yellows in New York State over a period from 1921 to 1938 is estimated at from 5 to 6 per cent of the normal crop (*Plant Disease Reporter* and its supplements), with losses reaching 70 to 80 per cent in some fields. The annual loss from this disease on Staten Island, alone, amounts to approximately \$1500, or about 6 per cent of the total crop value. The reduction in yield for the United States as a whole is probably not more than 2 per cent, since the disease has not yet been reported from some important lettuce-growing sections of the country.

Endive yellows would appear to be confined mainly to New York and New Jersey, with annual losses amounting to less than 5 per cent of the crop.

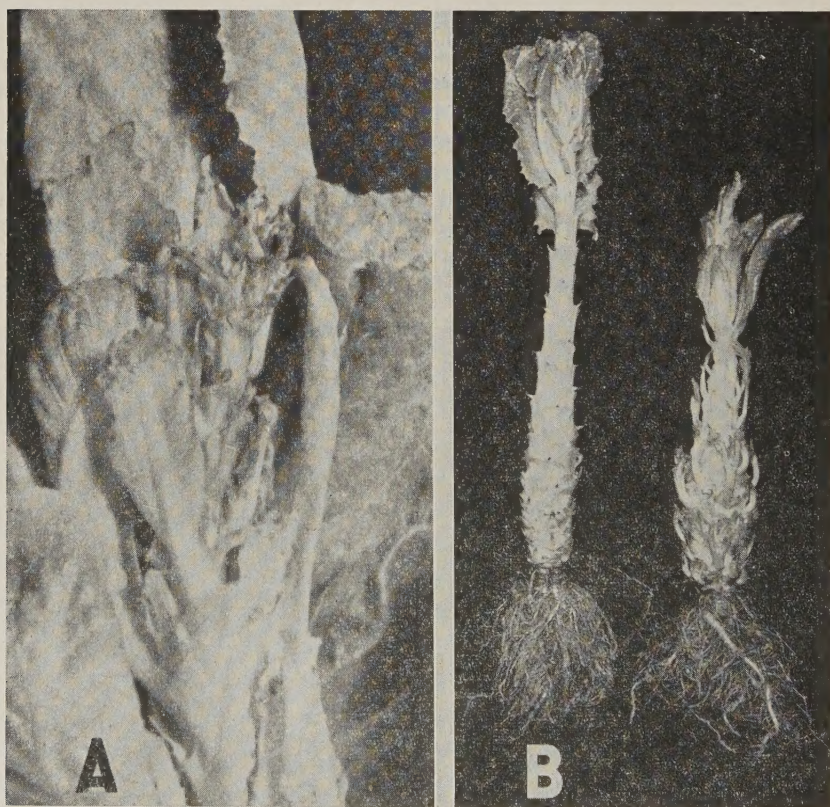


FIGURE 4. A, SPOTS ALONG MARGINS OF INNER LEAVES OF YELLOWS-INFECTED LETTUCE PLANT

B, LETTUCE SEED STALKS STRIPPED OF LEAVES SHOWING (LEFT) A HEALTHY PLANT, AND (RIGHT) PLANT INFECTED DURING HEAD FORMATION WITH SUBSEQUENT DEVELOPMENT OF LATERAL SHOOTS

SYMPTOMS

Lettuce yellows is readily recognized, prior to heading, by the yellowing, blanching, and curling of the inner leaves (figure 3). Another common symptom is the occurrence of small brown spots, composed of dried latex, along the margins of the inner leaves (figure 4, A). There is often a slight clearing of the veins, although this symptom is sometimes difficult to distinguish from normal venation. If the plants are affected after heading, the heart leaves are twisted, dwarfed, and curled; and as a result the head never becomes firm. There is usually an abnormal production of lateral, upright shoots in the axils of the leaves, caused, according to Kunkel (1931), by the stimulation of buds which ordinarily remain dormant. This phenomenon is most conspicuous after elongation of the flower stalk (figure 4,B), but may be observed prior to this if the outer leaves are pulled off of the diseased head. These lateral branches are at first upright in their habit of growth, but frequently bend downward later under their own weight (figure 5).

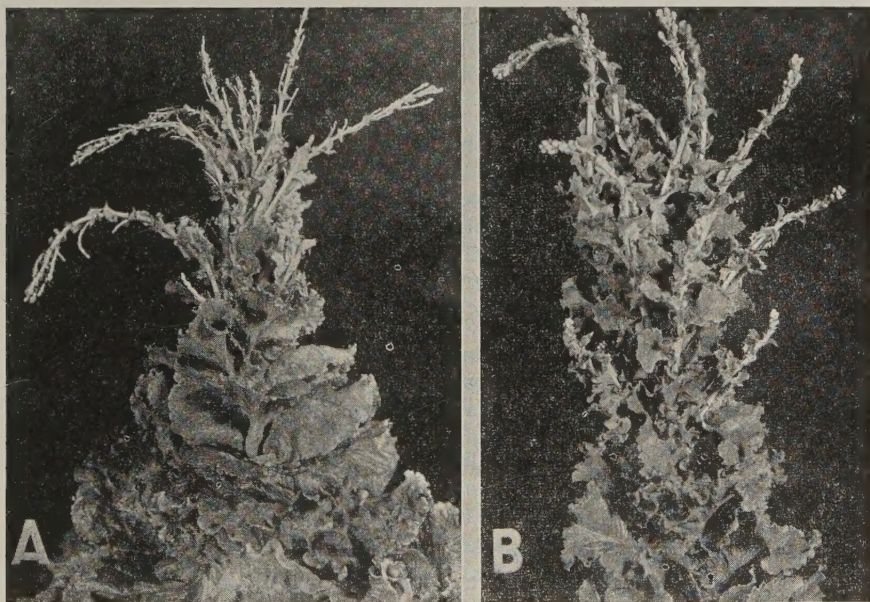


FIGURE 5. A, YELLOWED LETTUCE SEEDSTALK SHOWING WEAK ETIOLATED BRANCHES
B, HEALTHY LETTUCE SEEDSTALK

The flowers on diseased branches are commonly dwarfed and somewhat distorted. If seeds are produced by such flowers they invariably are dwarfed and sterile.

The symptoms of the disease on escarole are quite similar to those for lettuce, with the exception that the clearing of the veins and the twisting of the inner leaves are less pronounced (figures 6 and 7). The most striking symptoms on the curled-leaf endive are yellowing of the leaves and stunting of the entire plant.



FIGURE 6. LEFT, YELLOWS-INFECTED ESCAROLE (BROAD-LEAF ENDIVE) PLANT;
RIGHT, HEALTHY PLANT

ETIOLOGY

Names, characteristics, and classification of the virus

Of all the systems that have been proposed for nomenclature and classification of the plant viruses, perhaps that of Holmes (1939) shows best the relationships among the viruses. This system is the first to use Latin binomials for virus names.

Holmes classifies the aster-yellows virus as follows:

Kingdom: Vira

Division: Phytophagi

Class: Spermatophytophagi

Family: Chlorogenaceae

Genus: Chlorogenus

C. callistephi, type species; aster-yellows virus

var. *vulgaris*, type variety; typical strain

var. *californicus*, celery-yellows strain

var. *attenuatus*, heat-attenuated strain

The following names are listed by Holmes as synonyms of the typical aster-yellows virus: lettuce Rio Grande disease virus, lettuce white-heart virus, lettuce rabbit-ear virus, salsify-yellows virus, Erigeron-yellows virus, New York aster-yellows virus, virus of Gelbsucht der Sommerastern, and Callistephus virus 1. Serological and immunological relationships, filterability, and thermal inactivation of the virus in the plant juice have not been demonstrated. However, according to Kunkel (1937), thermal inactivation

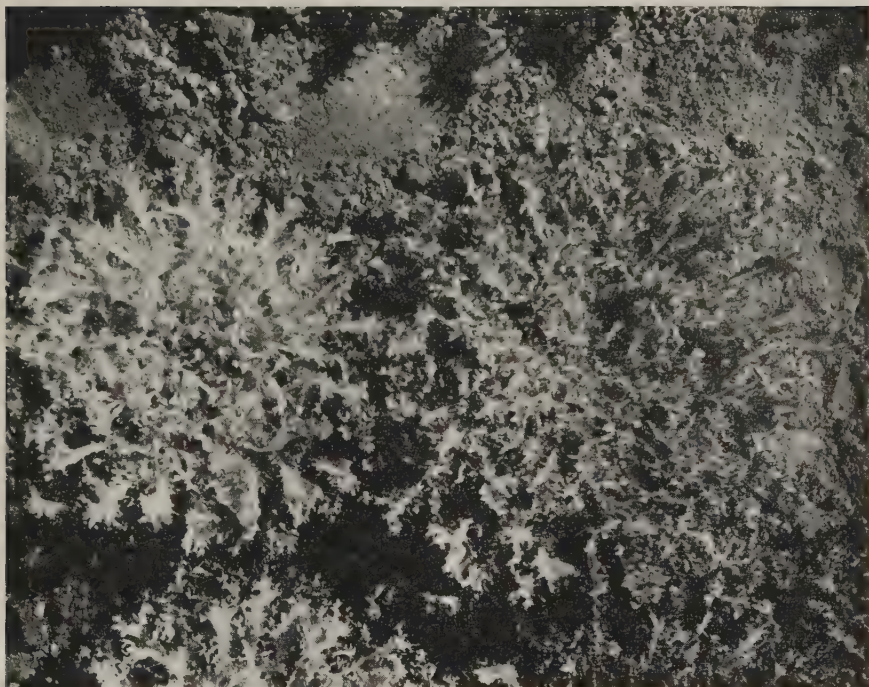


FIGURE 7. LEFT, YELLOWS-INFECTED CURLED-LEAF ENDIVE PLANT;
RIGHT, A HEALTHY PLANT

of the virus in the vector occurs in 12 days at 31°C . Kunkel further showed that short heat treatments of the virus in the vector result in a mild strain of the virus which remains unchanged on passage from plant to plant. Holmes calls this the "heat-attenuated strain."

Overwintering of the virus

Surveys made during the month of April, and covering most of the weed areas bordering farms, show that the common plantain, *Plantago major* L., is the principal, if not the sole, weed that overwinters the virus on Staten Island. Approximately 5 per cent of this species in some of these areas is affected.

Several of these weeds showing typical symptoms of yellows (chlorosis and distortion of the leaves) were brought into the greenhouse and potted. Non-viruliferous leafhoppers were placed on them, allowed to feed for two days, and then transferred to healthy aster plants. After an incubation period of approximately sixteen days, the aster plants showed symptoms of yellows, thus confirming the earlier diagnosis of the weed disease as yellows.

This virus is carried by leafhoppers from these overwintering suspects to lettuce and endive in neighboring fields.

Overwintering of the vector

There is considerable disagreement with respect to the manner in which the leafhopper vector overwinters. Osborn (1916) states that the exact method of overwintering of *M. divisus* in Maine is in doubt, although he obtained a few individuals from cages built in timothy fields in the early spring.

Kunkel (1926) believes that overwintering in the vicinity of New York City is in the egg stage. He failed to obtain adults from blocks of soil containing rye plants which were brought into a warm room in the spring and held for four days. In other experiments where similar rye plants were caged in the laboratory, he found nymphs and adults after twenty-five days. He also found that nymphs and adults were killed when subjected for a few hours to temperatures below 5° C., this experiment presumably being conducted in the laboratory.

Beckwith and Hutton (1929) are of the opinion that these leafhoppers overwinter as adults. This belief is based primarily on their failure to find nymphs on cranberry bogs in New Jersey until July, whereas adults could be found in May and June.

The following observations and experiments made by the writer on Staten Island suggest that this insect does not overwinter in the egg stage. Furthermore, if overwintering occurs in the adult stage, it probably does not take place in the weeds around cultivated areas.

Cheesecloth cages⁵ built over weeds and grasses around or within 1000 feet of cultivated areas failed to yield nymphs or adults of *M. divisus* as late as two months after their appearance⁶ in uncaged areas. When these insects appeared in the uncaged areas, the first form observed was the adult, nymphs not being seen until approximately 2½ weeks thereafter.

Several hundred adults of *M. divisus* placed in cheesecloth cages over weeds and grasses during the first week in October of 1937 were not alive the following spring, nor were nymphs present in these cages as late as four weeks after their appearance in uncaged areas.

Soil containing weeds, grasses, and debris from around cultivated areas was brought into the greenhouse during the month of April, placed under cheesecloth cages, and held at temperatures ranging from 60° to 85°F. for four weeks. Neither nymphs nor adults were present at the end of this period.

Daily sweepings with an insect net at the time of the first appearance of the leafhoppers in the spring showed that the adults appeared almost simultaneously over areas covering several acres, and that they were as numerous in the fields of lettuce as in the weed boundaries. This indicated that these leafhoppers originated at a point some distance away from the fields or bordering weeds.

An experiment was conducted to determine whether the leafhoppers first found in lettuce fields in the spring are viruliferous. On account of the relatively high percentage of overwintering yellowed plantain (25 per cent) in the weed borders of the fields sampled, some of the leafhoppers should have been viruliferous if they had overwintered in the bordering weeds. Three

⁵A total of 24 cages measuring 10 feet long, 8 feet wide, and 2 feet high were constructed in areas having had a heavy infestation of leafhoppers the previous fall.

⁶The earliest date recorded during the past five years on Staten Island is May 19 (1938).

hundred and fifty of these adults collected in lettuce fields were caged over like numbers of lettuce seedlings in the greenhouse, one leafhopper to each seedling. At the end of five weeks none of these plants had developed symptoms of yellows, indicating that (1) the leafhoppers were non-viruliferous when they first appeared and (2) none of these individuals had fed on diseased weeds prior to collection. Therefore it is likely that they had not moved into the fields from the weed boundaries.

Further evidence that the leafhoppers first to be found in the spring are commonly non-viruliferous is furnished by the fact that the yellows disease has never been observed on any suspect other than plantain until 27 days after the first appearance of the leafhoppers in the spring. This is of considerable significance, since a period of from 27 to 35 days generally elapses between the time the leafhoppers pick up the virus and the time when symptoms appear on susceptible plants.

Although it is evident that direct proof is lacking as to the manner in which the vector does overwinter, the circumstantial evidence cited leads the writer to believe that individuals overwintering in the egg stage probably make up a relatively small percentage of the total population of *M. divisus* in the spring. It would appear that the majority overwinter as adults in localities at some distance, perhaps several miles,⁷ from cultivated areas on Staten Island.

EPIPHYTOLOGY

DISPERSAL OF THE VECTOR⁸

Apparently few studies have been made either on the extent of the movements of this insect or on the effect of prevailing winds on the direction and distance covered by such movements. Stearns and MacCreary (1938) took data on leafhopper dispersal across Delaware Bay, using traps on lighthouses situated at various distances from shore. Of a total of 715 adults of *M. divisus* collected over a five-months period, 72.3 per cent were trapped three miles from land and 7.8 per cent nine miles from land. The largest numbers were collected on clear nights with high mean temperatures and light to moderate winds.

These experiments are noteworthy, since they indicate that this species can fly several miles over natural barriers when conditions are favorable.

Dispersal from cultivated areas into weed areas during harvest

The leafhopper population in weed areas bordering on lettuce beds often increases markedly during harvest. The majority of such beds on the smaller farms on Staten Island are bordered by a farm road on one end and by weeds on the other. In these beds harvesting usually proceeds from the road toward the weeds. It seems probable that the harvesters or cutters unknowingly drive the leafhoppers ahead of them into the weeds. If this is true, then such weeds serve not only as reservoirs of the virus but also as harbors for the leafhopper vector as well. The results of the following experiment tend to support this hypothesis.

⁷The results of observations and experiments by DeLong and Caldwell (1935) suggest that the potato leafhopper (*Empoasca fabae* Harris) overwinters in Florida and the Gulf States, whence it migrates in the spring to Ohio and other northern States.

⁸The use of the term "dispersal" in this paper conforms to that of Tutt (1902) and Severin (1933), who limit "dispersal" to flights within the natural breeding areas and "migration" to flights outside the natural breeding areas.

Several sweepings were made with an insect net in weed areas bordering on two lettuce beds immediately before and after harvest (approximately two hours apart). Harvesting in both beds proceeded from the road toward these weed borders. The numbers of leafhoppers collected in three series of twelve sweeps are shown in table 1.

TABLE 1. EFFECT OF HARVESTING ON THE DISPERSION OF THE LEAFHOPPER VECTOR FROM LETTUCE BEDS INTO ADJOINING WEEDS

Bed	Series	Number of leafhoppers collected in 12 sweeps			
		Before harvest		After harvest	
		Nymphs	Adults	Nymphs	Adults
1	1	0	2	17	33
	2	0	0	8	24
	3	0	0	4	11
2	1	2	3	12	25
	2	2	1	18	13
	3	0	2	4	25
Total collected.....		4	8	63	131

These data show that, during harvest, the leafhoppers were driven into the weeds adjoining the beds; the total number of leafhoppers after harvest was approximately 16 times greater than just before.

Dispersal from weed areas into cultivated areas

Dissemination of the aster-yellows virus is a function of vector dissemination, for the virus in itself is static with respect to movement from plant to plant. Hence the extent and direction of vector dispersion from weed areas into adjoining cultivated areas (escarole beds) can be determined from the incidence of yellows in these areas.

Counts of the incidence of yellows in four escarole beds, one of which is illustrated in figure 8, showed that the highest percentage of yellows occurred in the rows nearest the side bordered by weeds (figure 9). The percentage of yellows in succeeding endive rows in each of the beds was in inverse ratio to the distance in feet from these rows to the weeds. The distribution curves drop rather abruptly at first and then flatten out somewhat, indicating that the initial dispersal of the vector was rather limited in extent.

The effect of the weed borders as sources of the vector approaches a minimum as the curves flatten out. Had the beds been wider, supplemental counts would probably have shown an increase in the amount of disease as the spheres of influence of other vector sources were entered.

If the percentage of yellows in these beds is plotted against the logarithm of the distance in feet from the weeds to the observation point, the resulting curves are straight lines (figure 10). This suggests that the rate of vector dispersion over a given bed, as measured by the incidence of yellows, can be expressed by a constant. The value of this constant will vary from one bed to another depending upon the slope of the log distribution curves, which will be influenced by the distance the leafhopper jumps or is carried

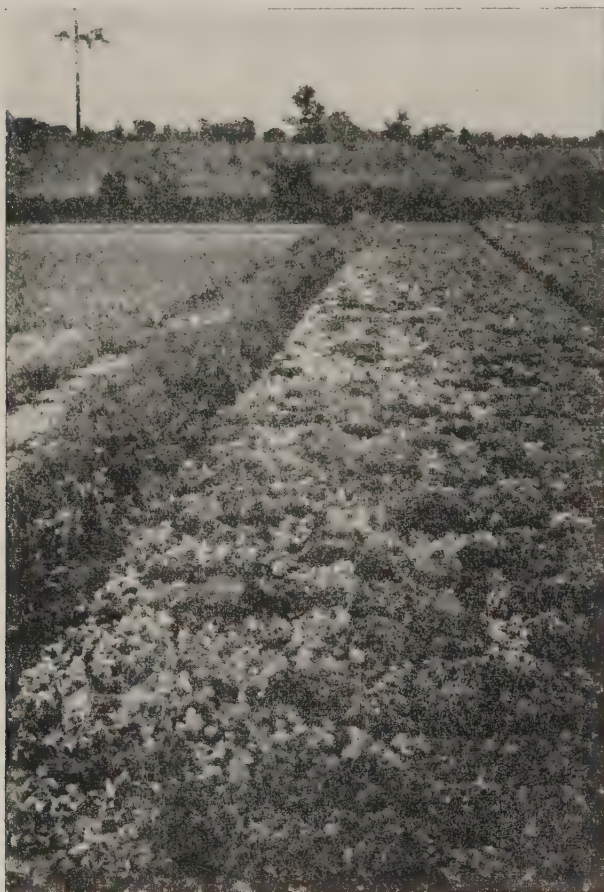


FIGURE 8. SPREAD OF THE YELLOWS DISEASE FROM A WEED BORDER INTO AN ESCAROLE BED (LEFT TO RIGHT)

See curve C in figures 9 and 10

by air currents, and the frequency of jumps. These, in turn, will be determined by (1) wind velocity and direction, (2) number and frequency of cultivations and overhead irrigations, (3) temperature, humidity, and rainfall, and (4) preference of the leafhopper for the particular plant on which it attempts to feed.

For example, curve A in figure 10 is somewhat steeper than the other three curves, indicating that the rate of dispersion of the vector in bed A was retarded by one or more of the above factors, as compared with the rate in the other three beds.

Given the two points where the log curve intercepts the coordinates, or given one intercept and the slope of the curve, one can then postulate (1) the potential percentage of infection⁹ in the weed borders, and (2) the

⁹The highest percentage that could be anticipated in the weed borders if all the weeds and the escarole were equally susceptible to yellows.

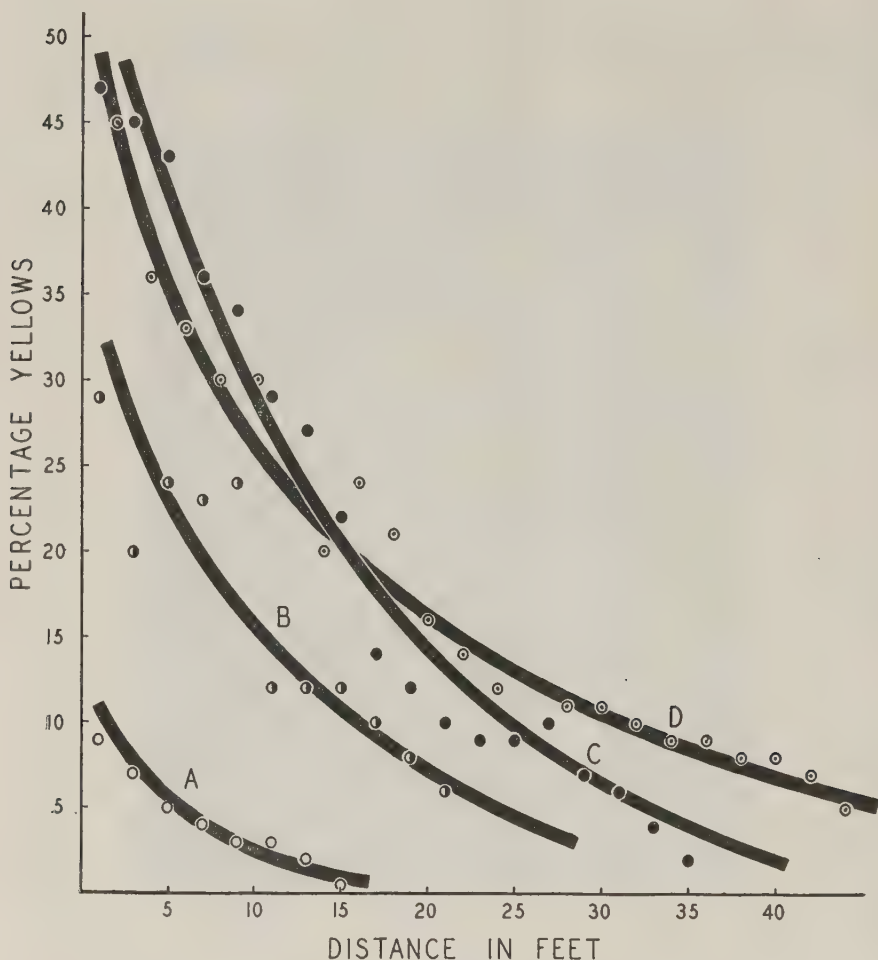


FIGURE 9. DISTRIBUTION CURVES SHOWING THE INCIDENCE OF YELLOWS IN FOUR ESCAROLE BEDS

distance in feet from the weeds to that point in the bed where these weeds no longer influence the incidence of yellows.

Dispersal of stained leafhoppers over a diversified crop area

Experiments were conducted to determine how far *M. divisus* would move over a four-weeks period of time, and what effect wind direction during that period would have on such movements. Since it had already been shown (table 1) that these leafhoppers sometimes move from crops into adjoining weed areas during harvest, a weed patch at one end of a recently harvested endive bed was chosen as the center of operations for the first experiment. That a considerable number of leafhoppers were

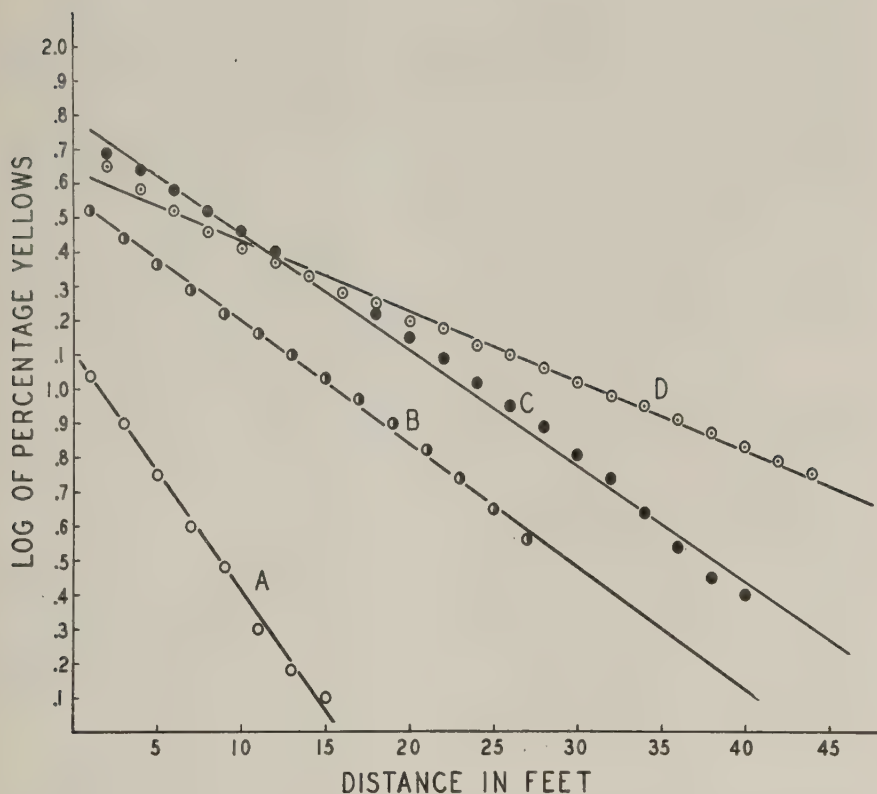


FIGURE 10. LOGARITHMIC CURVES OF ESCAROLE-YELLOWS DISTRIBUTION IN THE FOUR BEDS REPRESENTED IN FIGURE 9

present in this area is shown by the fact that 30 sweeps with an insect net yielded 75 adults of *M. divisus*.

A dust-dye mixture similar to that used by Clarke (1937)¹⁰ in tracing mosquito dissemination was blown into the leafhopper-infested weeds with a hand duster turned at high speed but regulated so that only 5 to 10 pounds per acre was applied. The dust was a mixture of 1 part of methyl-violet 3B concentrated powder and 9 parts of wheat flour. An area measuring approximately 300 square feet was dusted. It was hoped that dye particles would stick to some of the leafhoppers and thereby provide a means of identifying them later in near-by fields and beds.

The dye was applied on September 8 and collections of leafhoppers were made at four-day intervals from September 12 to October 8. Collecting stations measuring 100 square feet in area were established in various crops (spinach, beets, carrots, and endive) at different distances and directions from the dusted area, thirty sweeps with an insect net being made at each station on the days of collection.

¹⁰Further data in letter to author, dated September 22, 1936.

The leafhoppers collected at each station were taken to the laboratory, where they were examined by the following method for the presence of dye particles. A vial containing equal parts of absolute alcohol and glycerin was placed under a binocular microscope. The leafhoppers collected at a given station were then dropped one at a time into this mixture. Any particles of dye on their bodies were at once intensified, thus making relatively easy the determination of the number of dyed and undyed leafhoppers that had moved to the collecting stations.

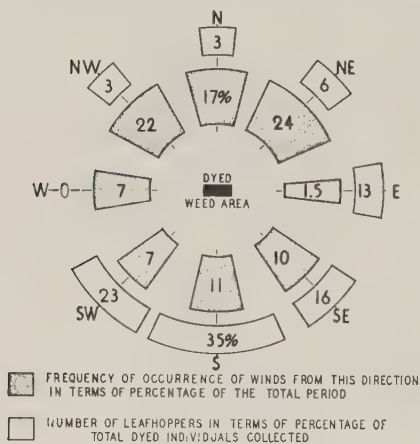


FIGURE 11. EFFECT OF WIND DIRECTION ON THE DISPERSAL OF STAINED *MACROSTELUS DIVINUS* OVER A DIVERSIFIED CROP AREA DURING A 30-DAYS PERIOD

The relationship between the frequency of occurrence of winds and the number of leafhoppers collected at the various stations is shown in figure 11.

The results of this experiment may be summarized as follows:

1. Although *M. divinus* was found to take the stain readily, only 2 per cent of the individuals collected were stained.
2. At stations 30 feet from the dusted area, stained leafhoppers were found 4 days after dusting.
3. At distances of 150 to 300 feet from this area stained leafhoppers were not found until 12 days after dusting.
4. At greater distances (400 to 500 feet) 17 days passed before stained leafhoppers were found.

5. No stained leafhoppers were ever found at stations more than 500 feet from the dusted area.

6. No stained leafhoppers were found on or after October 8, 26 days after dusting. In fact, there was a considerable reduction in numbers of unstained leafhoppers collected, as compared with that taken on the preceding day of collection.

7. Winds were from the *northwest*, *north*, and *northeast* for a total of 63 per cent of the whole test period. Seventy-four per cent of the dyed leafhoppers were collected *southeast*, *south*, and *southwest* of the dusted area.

8. Winds were from the *southwest*, *south*, and *southeast* 28 per cent of the period. Twelve per cent of the leafhoppers were collected *northeast*, *north*, and *northwest*.

9. There is a close correlation between frequency of winds from the *east* and *west* and numbers of leafhoppers collected *west* and *east*, respectively, of the dusted area.

Dispersal of stained leafhoppers over a uniform crop area

A possible criticism of the technique used in the preceding experiment is that wind direction may not have been as important in determining leafhopper density as may have been the preference of the leafhopper for a

particular crop in which a collecting station was located. In addition, cultivating, irrigating, and harvesting operations may not have been alike on all sides of the center of operations.

In a second experiment a timothy field of uniform stand measuring 500 by 700 feet was chosen as the experimental area. Since this area was covered with but one crop, the only factors likely to influence leafhopper density would be wind direction and wind velocity.

Approximately 2000 adults of *M. divisus* were collected and placed in a cheesecloth cage. The same dust-dye mixture used in the first experiment (methyl-violet 3B concentrated powder, and wheat flour) was blown into the cage with a plunger hand duster. The leafhoppers were then released in the center of the above timothy field.

Collecting stations were established at 50-foot intervals on imaginary lines extending north, east, south, and west of the center or point of release. There was a total of four stations in each of the four directions, the farthest removed being 200 feet from the point of release.

The leafhoppers were released on August 19 and collections (30 sweeps with an insect net) were made at five-day intervals, starting on August 24, at each of the 16 stations. The last collections of stained leafhoppers were made on September 8. Rainfall began on September 12 and prevented any further attempts at collection until September 23, at which date no stained leafhoppers could be found at any station.

The method used to determine the number of stained individuals collected at each station was the same as that used in the first experiment. The numbers collected at each station are shown in table 2.

TABLE 2. DISPERSAL TREND OF THE VECTOR WITH REFERENCE TO DIRECTION AND DISTANCE FROM A GIVEN POINT IN A TIMOTHY FIELD

Station	Distance in feet from point of release	Direction from point of release	Number of stained leaf- hoppers collected						Total collected from each station
			August		September				
			24	29	3	8	23		
1	50	North	0	0	4	2	0	6	
2	50	East	1	8	10	3	0	22	
3	50	South	1	0	6	0	0	7	
4	50	West	0	1	0	0	0	1	
5	100	North	0	1	0	0	0	1	
6	100	East	0	1	1	3	0	5	
7	100	South	1	0	0	0	0	1	
8	100	West	0	0	0	2	0	2	
9	150	North	0	0	1	4	0	5	
10	150	East	0	0	0	1	0	1	
11	150	South	0	0	0	2	0	2	
12	150	West	0	0	0	0	0	0	
13	200	North	0	0	0	0	0	0	
14	200	East	0	0	0	1	0	1	
15	200	South	0	0	0	0	0	0	
16	200	West	0	0	0	1	0	1	
Total number of leafhoppers collected on each date. . . .			3	11	22	19	0	55	

According to the above data, the peak of leafhopper collections occurred on September 3 (15 days after release), when a total of 22 individuals was collected. The majority were taken at a distance of 50 feet from the point of release. No dyed leafhoppers were collected 200 feet from the point of release until after 20 days (September 8), when 2 individuals were taken.

The effect of any variations in mean air temperatures¹¹ or in wind velocity on leafhopper dispersal during these two experiments is not apparent, for the distances covered by the leafhoppers in a given period of time were approximately the same in both experiments.

The relationship between frequency of winds and numbers of stained leafhoppers found at the collecting stations is shown in figure 12. The correlation

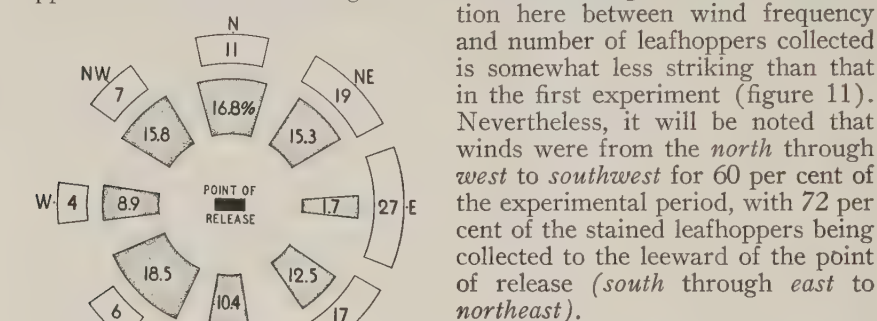


FIGURE 12. EFFECT OF WIND DIRECTION ON THE DISPERSAL OF STAINED MACROSTELIS DIVINUS OVER A UNIFORM CROP AREA (TIMOTHY FIELD) DURING A 35-DAYS PERIOD

here between wind frequency and number of leafhoppers collected is somewhat less striking than that in the first experiment (figure 11). Nevertheless, it will be noted that winds were from the *north* through *west* to *southwest* for 60 per cent of the experimental period, with 72 per cent of the stained leafhoppers being collected to the leeward of the point of release (*south* through *east* to *northeast*).

The results of these two experiments indicate that (1) wind direction may play an important part in determining the direction of leafhopper dispersal over relatively short distances, (2) wind velocity and mean air temperatures are probably of lesser importance in this respect, and (3) the leafhoppers do not move in perceptible numbers much farther than 200 feet in four

weeks, where favorite host plants are present.

CONTROL

ERADICATION OF WEED RESERVOIRS OF THE VIRUS AND WEED HARBORS OF THE VECTOR

Weiss (1925, 1929), White (1931), and Jones and Riker (1931) suggest that the eradication of perennial weed susceptibles of the virus around aster plantings should control aster yellows. Apparently the theory was not put to the test by any of these workers. However, they point out that this method of control is difficult to apply in actual practice.

Since the writer has shown that (1) weeds bordering endive beds are reservoirs of the virus and harbors of the vector, and (2) the insect vector does not normally travel more than 200 feet over feeding areas in several weeks' time, the next step was to test the effect of weed eradication on the control of lettuce and endive yellows.

¹¹Actually the mean air temperatures were appreciably higher during the second experiment.

Experiments with herbicides

Preliminary tests were made to determine the efficiency of a number of herbicides, including sodium chlorate crystals, and sodium chlorate, Atlacide,¹² Sinox,¹³ Sinox Special,¹³ and Elgetol¹³ solutions. The crystals were broadcast by hand at the rate of 500 pounds per acre. The sodium chlorate solution, 1 pound in 1 gallon, and the Atlacide solution, 1½ pounds in 1 gallon, were applied with a sprayer at the rate of 450 gallons per acre; Sinox and Sinox Special, 1 pound in 50 gallons, and Elgetol, 2 pounds in 50 gallons, with a sprayer at 480 gallons an acre.

Four ounces of Vatsol¹⁴ was added to each 12 gallons of sodium chlorate and Atlacide, to improve the latter's wetting properties.

The principal weeds in the test areas were: common ragweed (*Ambrosia artemisiifolia* L.), giant ragweed (*A. trifida* L.), lamb's quarter (*Chenopodium album* L.), common plantain (*Plantago major* L.), smartweed (*Polygonum* sp.), purslane (*Portulaca oleracea* L.), pigweed (*Amaranthus* sp.), *Galinsoga parviflora* Cav., and various species of grasses.

The best weed control was obtained with sodium chlorate crystals. In some instances the growth of weeds in areas so treated was inhibited for as long as four months afterwards. However, all materials, with the exception of Sinox and Sinox Special, gave adequate control of both weeds and grasses for periods of from five to six weeks.

Since the results of the above tests showed that border weeds could be destroyed or their growth inhibited for several weeks, experiments were started on three farms to determine whether weed eradication would control lettuce and endive yellows.

Effect of weed eradication on the incidence of yellows

On farm 1, sodium chlorate crystals were broadcast in the early spring over weed areas measuring about one-third of an acre and bordering certain of the farm roads and plant beds (figure 13). A portion of the endive (escarole) plants raised from seed sown in bed A were transplanted to a bed within the weed-free area, a second portion to a bed a short distance away from this area and bounded by weeds on two sides, and a third portion to two beds at distances of 325 and 500 feet from the weed-free area and bounded by weeds on three sides. The escarole plants were approximately 5 inches tall at this time.

Data were taken on the amount of yellows in each bed within five days of harvest (figure 13). These show that all of the beds outside of the weed-free area had considerably more yellowed plants than had the bed within this area.

In a second experiment on farm 1, a portion of the escarole plants in bed B in the weed-free area were transplanted to a bed in the same area, a second lot to a bed bordered on one end and along most of one side by weeds, and a third lot left in the original seedbed. The plants were approximately the same size as those in the preceding experiment. Data were taken on the number of yellowed plants in the beds at harvest (figure 13). It might seem from the yellows developing in plant bed B (13 per cent) that

¹²A chlorate to which has been added a penetrant, and a safener against fire hazards.

¹³Dyestuffs.

¹⁴Sodium salt of an alkyl ester of sulfosuccinic acid.

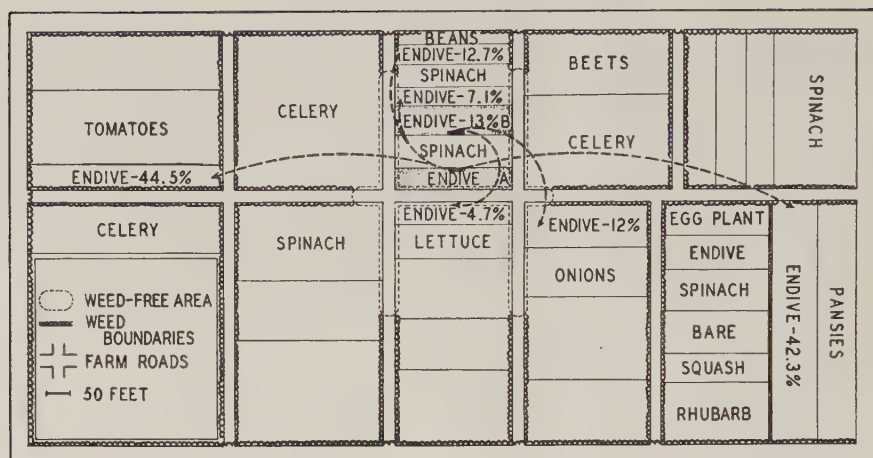


FIGURE 13. DIAGRAM OF A WEED-ERADICATION PROJECT INVOLVING THE CENTRAL PORTION OF A FARM (FARM I), SHOWING TWO ENDIVE SEEDBEDS (A AND B) AND THE BEDS INTO WHICH THE ENDIVE SEEDLINGS WERE SUBSEQUENTLY TRANSPLANTED

a reversal in the general trend had occurred. A possible explanation is that the removal of plants from this bed left many leafhoppers behind to attack the endive plants maturing in this bed. Then, too, the grower may have exercised some selection in digging transplants, thus leaving a few more plants with yellows than were removed.

In three supplementary experiments on this farm, from 100 to 400 Romaine lettuce plants, approximately 4 inches tall, were transplanted from the greenhouse into various beds within the weed-free area, with like numbers being transplanted into beds bordered by weeds on one or more sides. Data taken in each plot six weeks after transplanting and three to five days before harvest showed that an average of 11 per cent of the plants in the weed-free area were yellowed, as compared with an average of 39 per cent in those plots bordered by weeds.

A second and similar project was started at the same time on farm 2 (figure 14), using sodium chlorate crystals to eradicate the weeds in an area of approximately one-third of an acre. One hundred Romaine and 100 Iceberg lettuce plants were transplanted from a greenhouse into plot a, and a like number into plot b. Data taken six weeks later showed that only 9 per cent of the plants in the weed-free area (plot a) were affected with yellows, as compared with 31 per cent of those in the area bounded by weeds (plot b). Data for two endive beds containing plants of identical age and source are also shown in figure 14. The bed having the lesser number of yellowed plants (2 per cent) is within the area cleared of weeds.

Another weed-eradication project was conducted on farm 3 (figure 15). The weeds in the cleared area, measuring about one-sixth of an acre, were eradicated with sodium chlorate crystals. Two hundred Romaine and Iceberg lettuce seedlings were transplanted from the greenhouse into each of the plots designated on the farm outlined as a, b, c, and d. Data taken eight weeks later revealed that none of the plants in plots a and b in the

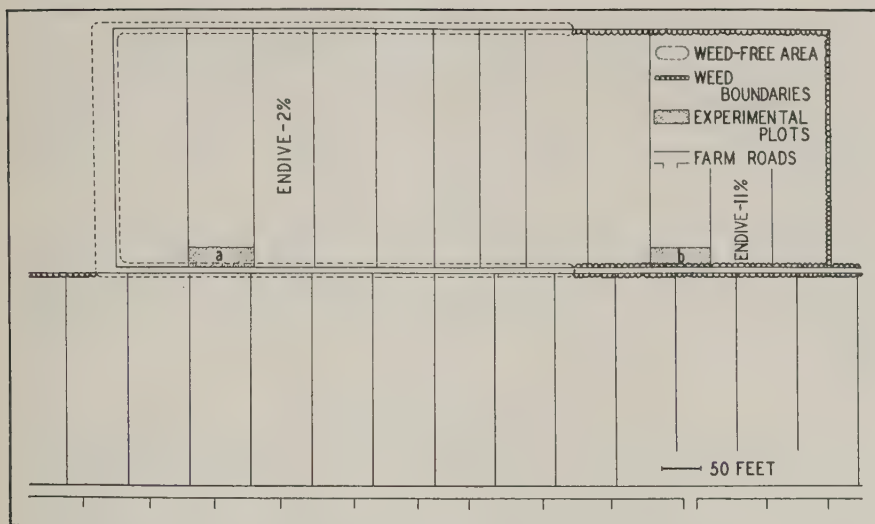


FIGURE 14. DIAGRAM OF A WEED-ERADICATION PROJECT INVOLVING THREE SIDES OF A FARM (FARM 2)

One experimental lettuce plot (a) is within the weed-free area and the other (b) is bounded by weeds

weed-free area had developed symptoms of yellows, while 26 and 33 per cent of the plants in weed-bordered plots c and d, respectively, were yellowed.

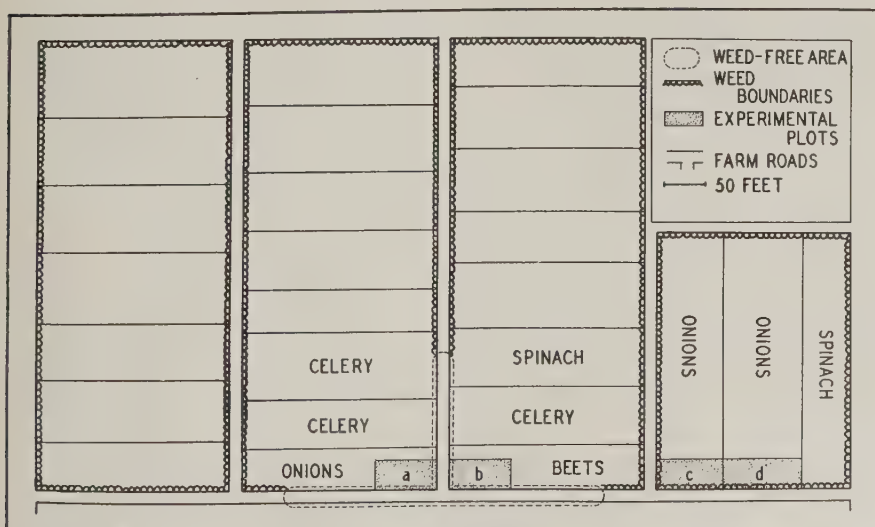


FIGURE 15. DIAGRAM OF A WEED-ERADICATION PROJECT INVOLVING A PORTION OF ONE SIDE OF A FARM (FARM 3)

Two experimental lettuce plots (a and b) are within the weed-free area and the others (c and d) are bounded by weeds

The data from the above experiments show that eradication of weeds bordering on cultivated areas results in an appreciable reduction in the amount of lettuce and endive yellows. While, in the main, relatively small numbers of plants were used in the lettuce test plots, comparable results probably would have been obtained with larger numbers. The results of experiments involving entire beds of endive on farms 1 and 2 are suggestive in this connection.

It should be emphasized that all of the lettuce plants used in these experiments were raised in coldframes and transplanted to field beds. The length of time during which they were exposed to vector feeding was six weeks. Had the seed been drilled in the beds, the length of exposure to the vector would have been increased to seven or eight weeks, which probably would have resulted in an increase in the number of yellowed plants at harvest.

Cost of weed eradication

The cost of weed eradication depends mainly upon the kind of herbicide used, the method of application, and the size of the weeds. Sodium chlorate crystals, when used at the rate of 500 pounds per acre, cost approximately \$35. The time required for application is about three hours per acre, which, at 40 cents an hour, makes the total cost roughly \$36 per acre of weeds.

Atlacide and sodium chlorate sprays applied at the rate of 450 gallons an acre totaled approximately \$68 and \$33, respectively, including the Vatsol spreader and labor charges.

Applications of Elgetol at 480 gallons an acre averaged about \$44, including labor costs.

ERADICATION OF DISEASED CROP PLANTS FROM BEDS

Weiss (1925), Hamilton (1932), and others have recommended roguing as a control measure for aster yellows. There seem to be few experimental data to support this practice. Kunkel (1929) reports that he obtained a considerable reduction in yellows in asters by protecting the plants with wire-screen fences and roguing the yellowed plants as they appeared. It is not apparent whether roguing was practiced in the unprotected plots. However, Pepper and Haenseler (1939) report an appreciable reduction in yellows in lettuce where diseased plants were rogued five times at weekly intervals. Gaines¹⁵ found that roguing was of no value in controlling yellows of head lettuce in Wayne County, New York.

Experiments were conducted by the writer on three lettuce beds to determine whether roguing yellowed plants would result in a decrease in the amount of yellows. These beds were also being used in dusting experiments for the control of the leafhopper vector. In one-third of both dusted and undusted plots, the yellowed plants were rogued when they first appeared and at stated intervals thereafter. Pyrethrum-sulfur dust was applied immediately after roguing to those plots scheduled to be so treated. Thus comparisons could be made among (1) plants rogued and dusted, (2) plants rogued but not dusted, (3) plants not rogued but dusted, and (4) plants not rogued and not dusted. Data taken on the amount of yellows in each plot within five days of harvest are shown in table 3. The percentages given are averages of two replications.

¹⁵Gaines, J. G. Muck crop disease investigations. Williamson, New York, Cooperative Vegetable Assoc. fellowship. Mime. rept. 1925.

TABLE 3. EFFECT OF ROGUING WITH AND WITHOUT COINCIDENTAL DUSTING ON THE INCIDENCE OF YELLOWS IN LETTUCE

Bed	Average number plants per plot	Date of roguing	Percentage of yellowed plants			
			Rogued		Not rogued	
			Not dusted	Dusted	Not dusted	Dusted
1	641	Aug. 30	30.8	23.7	23.6	19.0
2	404	Sept. 8	10.4	11.1	8.2	8.8
3	348	Sept. 8 Sept. 1, 9, 28	7.9	3.6	5.3	2.8
Average percentage yellows.			16.4	12.8	12.3	10.2

These data show that there is a slight but consistent increase in the incidence of yellows in rogued over unrogued plots regardless of subsequent dusting. Therefore, there would appear to be no advantage in roguing yellowed plants from small lettuce plantings. The most probable explanation is that roguing disturbs the leafhoppers on the diseased plants and, as a result of local movement and feeding, neighboring plants become infected.

PROTECTION THROUGH THE APPLICATION OF INSECTICIDES

The application of spray and dust protectants to asters by various workers has not resulted in either marked or adequate control of yellows. Among the different treatments, the most prominent have been spraying with pyrethrum, nicotine, bordeaux mixture, and white oil, and dusting with pyrethrum and nicotine.

Pepper and Haenseler (1939) report satisfactory control of yellows in lettuce with a derris-sulfur-talc dust (0.75 per cent rotenone) and with a pyrethrum-sulfur-talc dust (0.3 per cent pyrethrins). So far as the writer knows, this is the only work thus far published on the control of yellows in lettuce by dusting.

Preliminary experiments were made by the writer with sulfur and derris dusts, and with pyrethrum-sulfur, and pyrethrum-derris-sulfur dust mixtures. The pyrethrin content of the pyrethrum dusts varied from 0.025 to 0.15 per cent, while the rotenone content of the derris dust was fixed at 1 per cent. Weekly applications were made with a rotary hand duster, at rates of from 35 to 50 pounds per acre, beginning when the plants were from 3 to 5 inches tall and continuing until harvest. Data were taken on the number of yellowed plants at harvest in dusted and check plots.

The results of these experiments demonstrated that sulfur alone does not give satisfactory control of yellows even if relatively heavy applications (50 pounds per acre) are made, and that an increase in the rate of application of the other materials above 35 pounds an acre is not warranted. Pyrethrum-sulfur dusts, in general, give satisfactory control of the disease, and their effectiveness is not enhanced by the addition of derris. However, derris dust alone gives control of yellows almost equivalent to that obtained with pyrethrum-sulfur mixtures.

Since the sulfur concentration of the pyrethrum-sulfur dusts usually varied inversely with the pyrethrin content, it was impossible to correlate their efficiency with pyrethrin concentrations. In the following experiments,

dusts with varying pyrethrin content but with fixed sulfur concentrations were used.

Three pyrethrum-sulfur dusts¹⁶ with pyrethrin levels of 0.15, 0.20, and 0.25 per cent were employed. Each contained 37.8 per cent dusting sulfur. The remainder of the dusts was composed of pyrophyllite,¹⁷ varying inversely with the amount of pyrethrum powder from 54.6 to 49.6 per cent. A derris dust made up of 25 per cent derris powder (4 per cent pure rotenone), 25 per cent 325-mesh sulfur, and 50 per cent fibrous talc was also used.

Randomized plots of approximately 800 plants each were laid out on two farms. All plants were grown in coldframes and transplanted to field beds before they were dusted.

The dusts were applied with a rotary hand duster, equipped with two outlets, at the rate of 35 pounds per acre, beginning when the plants were from 3 to 4 inches tall.

Since no records were taken on the leafhopper population in any of the plots, the criterion for control is the percentage of diseased plants in the plots at or within one week of harvest (table 4).

TABLE 4. CONTROL OF YELLOWS IN ROMAINE LETTUCE BY 5 WEEKLY APPLICATIONS OF PYRETHRUM-SULFUR DUSTS WITH 0.15, 0.20, OR 0.25 PER CENT PYRETHRINS, AND 1 PER CENT ROTENONE DUST

Treatment	Number of replications	Mean* percentage yellowed	
		Experiment 1	Experiment 2
Pyrethrum-sulfur			
0.15 per cent pyrethrins.....	3	14.6	13.3
0.20 per cent pyrethrins.....	3	8.9	7.3
0.25 per cent pyrethrins.....	3	14.4	13.7
1 per cent rotenone-sulfur.....	3	9.7	7.6
Check.....		49.1	32.2

*The least difference between means necessary for significance for odds of 19:1 is 3.79 in experiment 1, and 3.28 in experiment 2.

These data show that all dusts give significant control of yellows, and that the 1 per cent rotenone dust and the 0.20 per cent pyrethrin dust are significantly better than the other materials. A significant increase in control results if the pyrethrin level is raised from 0.15 to 0.20 per cent. However, if the pyrethrins are again increased from 0.20 to 0.25 per cent, the control obtained is appreciably decreased. If 0.20 per cent were the most effective pyrethrin concentration, one would expect an increase to result in at least equivalent control. The fact that this does not occur is probably due to some factor other than pyrethrin content. In this connection, it was noted that the 0.25 per cent dust did not flow through the duster as readily or as evenly as did the other materials. This may account for its poor showing.

Cost of lettuce dusting

The cost of five weekly applications of 1 per cent rotenone-sulfur dust at the rate of 35 pounds per acre should not exceed \$18.50 an acre. This may be itemized as follows:

¹⁶The pyrethrum base was dry pyrocid mixed with the other ingredients.

¹⁷This inert diluent is composed of aluminum silicate.

170 pounds of rotenone-sulfur dust	\$16.00
5 hours of labor	2.00
Use of duster	0.50
	\$18.50

The total cost of similar applications of pyrethrum-sulfur dust containing 0.20 per cent pyrethrins will be approximately \$21.25 (170 pounds of dust—\$18.75).

If there are 43,560 lettuce plants in an acre (planted on 1-foot squares), and if 50 per cent of these, in a late-summer crop, do not produce marketable heads from causes other than yellows (tip-burning, bolting, etc.), the number of remaining plants will total 21,780.

If, through dusting, the loss from yellows in these plants can be reduced but 5 per cent, the resulting increase in number of marketable heads would amount to 1089, whether the reduction in yellows is from 90 to 85 per cent or from 10 to 5 per cent. At 50 cents per box of 24 heads, the returns would be \$27.00 per acre, or more than enough to cover the cost of dusting.

Data over a four-years period indicate that the amount of control resulting from dusting is likely to be considerably more than 5 per cent; hence dusting, especially with rotenone-sulfur dust, would appear to be a rather profitable practice.

PROTECTION BY MEANS OF ARTIFICIAL BARRIERS

Kunkel (1929) and Tilford (1930) have shown that asters may be partially protected from viruliferous leafhoppers by the use of wire-screen fences which have a mesh of 18 wires to the square inch. Jones and Riker (1931) demonstrate that the most consistent control of this disease is obtained with cloth houses having tops and sides of a mesh not coarser than 22 threads to the inch. Where side walls alone were used, the reduction in yellows in two experiments was from 90 to 44 per cent, and from 95 to 82 per cent.

Attempts were made to duplicate these results with lettuce grown in cloth enclosures, cloth-screened greenhouses, and cloth-covered coldframes.

Cloth enclosures

A rectangular enclosure 6 feet high, 12 feet wide, and 18 feet long was constructed on July 23 over a portion of a bed of Romaine lettuce seedlings which were approximately $1\frac{1}{2}$ inches tall. The sides of the enclosure were made of aster cloth measuring 22 threads to the square inch. The top was left uncovered. The seedlings were thinned on July 28. Counts on the number of yellowed plants inside the enclosure and in two adjacent unprotected plots were made at three-day intervals. No attempt was made to rogue the yellowed plants in any plot.

Symptoms of yellows appeared in the enclosure 9 days after they were seen in the unprotected plots (figure 16). The increase in diseased plants in the enclosure during the 24-day period preceding harvest (September 22) amounted to 12 per cent, while the corresponding figure for the unprotected plots over the same period was 25 per cent. The delay in appearance and the reduction in amount of the disease suggests that shortening the period of exposure to viruliferous leafhoppers by growing the lettuce plants in

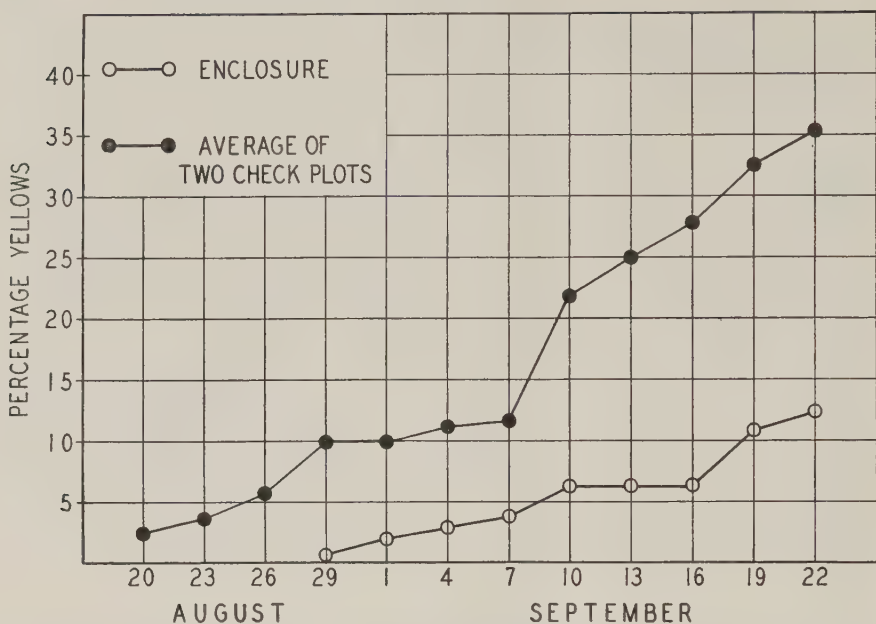


FIGURE 16. PERIODIC INCREASE IN LETTUCE YELLOWS IN A PLOT ENCLOSED WITH ASTER CLOTH, AND IN TWO ADJACENT UNPROTECTED PLOTS

cloth-protected seedbeds might result in some control of yellows. Several experiments were made to test this theory.

Cloth-screened greenhouses

In one experiment, Romaine lettuce seed was sown in a greenhouse, the windows and doors of which were screened with aster cloth to exclude leafhoppers. At the same time a quantity of the same lot of seed was sown in rows 24 inches apart in a field bed.

At the end of three weeks (September 19) the plants from the greenhouse-sown seed were transplanted into the field bed so that there were alternating rows of plants from field-sown seed, and plants from greenhouse-sown seed. The plants in both series were approximately 4 inches tall and showed no symptoms of yellows. Counts on the number of yellowed plants, which were made five weeks after transplanting and within four days of harvest, are shown in table 5.

These data show that protection of the young plants prior to transplanting resulted in a delay of 14 days in the appearance of yellows, and a reduction of 24.5 per cent in the number of diseased plants.

In another experiment a quantity of Big Boston lettuce seed was sown in a cloth-screened greenhouse and a similar quantity in a field bed. Four weeks later 200 plants from the greenhouse-sown seed were transplanted to a bed adjoining that containing the field-grown plants. Counts were made on the amount of yellows in the lettuce at harvest, which was about six

TABLE 5. CONTROL OF YELLOWS IN ROMAINE LETTUCE BY GROWING THE SEEDLINGS IN A CLOTH-SCREENED GREENHOUSE AND TRANSPLANTING TO A FIELD BED

Source of plants			
Greenhouse		Unprotected field bed	
Number of plants per row	Percentage yellowed	Number of plants per row	Percentage yellowed
38	15.8	40	35.0
40	12.5	37	48.7
40	7.5	39	43.6
39	12.8	39	28.2
40	20.0	40	40.0
39	5.5	40	20.0
Average percentage yellowed.....	12.3		36.8
Date of appearance of yellows, October 8		Date of appearance of yellows, September 24	

weeks after transplanting. These showed that 10 per cent of the plants originating in the greenhouse were diseased, as compared with 33 per cent of the plants from field-sown seed. The disease appeared in the plants from the greenhouse three weeks after it did in the field-grown plants.

Cloth-covered coldframes

A slight modification of the method used to protect the plants in the preceding experiments was utilized in a third experiment. Iceberg lettuce seed was sown in a coldframe, which was then covered with aster cloth. The cloth was not lifted or otherwise disturbed until the plants were transplanted to a field bed $3\frac{1}{2}$ weeks later (August 25). This bed adjoined a second bed containing Iceberg plants of the same age but from field-sown seed. Counts were made on the amount of yellows in both beds at harvest, 5 weeks later (table 6).

Again, a considerable delay in the appearance of, and a reduction in the total amount of, yellows followed when the seedlings were grown in a

TABLE 6. CONTROL OF YELLOWS IN ICEBERG LETTUCE BY GROWING THE SEEDLINGS IN CLOTH-COVERED COLDFRAMES AND TRANSPLANTING TO A FIELD BED

Source of plants			
Cloth-covered coldframe		Unprotected field bed	
Number of plants per plot	Percentage yellowed	Number of plants per plot	Percentage yellowed
347	8.0	363	34.2
352	7.4	345	32.5
349	6.6	358	42.5
Average percentage yellowed	7.3		36.4
Date of appearance of yellows, September 15		Date of appearance of yellows, September 2	

seedbed protected from viruliferous leafhoppers. The shading afforded by the aster cloth did not appear to be harmful, since only 3 per cent of the plants from the coldframe failed to head, as compared with 4 per cent in those plants from field-sown seed.

The results of these experiments show that an appreciable reduction in yellows in lettuce follows when the seedlings are protected from the vector prior to being transplanted to the field, thus confirming the hypothesis previously advanced.

DISCUSSION OF PRACTICAL APPLICATIONS

It is apparent from the data, and from observations on the feeding habits and dissemination of the leafhopper vector that reliance upon any single control measure for the yellows disease can hardly be justified. However, as combination control measures, (1) protection of the young plants by cloth coverings, (2) weed eradication, and (3) dusting with insecticides would seem to offer considerable promise if the limitations of each are fully appreciated.

The protection of seedlings, either in cloth-covered coldframes or in screened greenhouses, is in itself of little value if the vector is allowed to hide or multiply in waste areas adjacent to the beds into which the seedlings are to be transplanted. Since certain of the weeds in these areas also carry the virus over the winter, weed eradication may well be included in a yellows-control program.

Although the weed harbors of the vector on one farm may be destroyed, viruliferous leafhoppers may be carried by winds into the weed-free area from neighboring farms. Consequently it is necessary to supplement protection of the young plants, or weed eradication with applications of pyrethrum-sulfur or rotenone-sulfur dust.

Some attention should also be given to farm planting so that yellows-susceptible crops are not located in contiguous beds. Data and numerous observations show that when vector-infested crops are harvested, there is a trend towards mass movement of the vector in the direction in which harvesting is proceeding. If such movement were directed toward susceptible crops in adjacent beds, it would be extremely difficult, if not impossible, to cope with the influx of leafhoppers.

A control schedule for lettuce and endive yellows based on the facts brought out in this paper should include two or more of the following practices:

1. Protection of the seedlings by raising them in screened greenhouses or cloth-covered coldframes.

2. Transplantation of these seedlings into beds which are separated from weed areas and yellows-susceptible crops by distances of at least 200 feet. On most small farms this might require eradication of certain weed areas. Where this is not feasible because of the size of the weed patches involved, or for other reasons, the beds should be to the windward of the weeds with respect to the seasonal prevailing winds.

3. Weekly applications of either pyrethrum-sulfur dust, containing at least 0.15 per cent pyrethrins, or 1 per cent rotenone-sulfur dust, at the rate of 35 pounds per acre, starting at transplanting time and continuing until within 10 days of harvest.

A combination of practices 1 and 3 may suffice at present for satisfactory control of yellows on most farms.

SUMMARY

An investigation of the yellows disease of lettuce and endive, a limiting factor in the production of late-summer and fall crops on Staten Island, was conducted during the years 1935 to 1939.

One additional genus (*Cichorium endivia* L.) including two varieties, curled-leaf endive, and broad-leaf endive, or escarole, are reported as additions to the 170 species of plants previously reported as susceptibles of the Eastern aster-yellows virus.

Experiments where viruliferous leafhoppers were caged over 25 plants each of 23 varieties and strains of lettuce showed that all are equally susceptible to the yellows virus. Any varietal differences that may be observed in the field are believed due to preferential feeding on the part of the vector.

The disease on lettuce has been reported from the principal lettuce-producing States in this country and from Bermuda and Ontario. Yellows in endive occurs principally in lower New York State and New Jersey. Average losses are estimated at less than 6 per cent of the normal lettuce and endive crop.

The characteristic symptoms of the disease on both lettuce and endive are yellowing, stunting, and twisting of the leaves. Other abnormalities are discussed.

On Staten Island the virus has been found to overwinter chiefly on the common plantain, *Plantago major* L., from which it is carried by the vector to lettuce and endive plantings.

The exact manner of overwintering of the vector on Staten Island has not been determined. Circumstantial evidence suggests that overwintering seldom if ever occurs in the egg stage, and that overwintering may occur in the adult stage at a considerable distance from cultivated areas.

Studies on the dispersion of the vector into and from weeds adjacent to endive beds reveal that the vector is driven into the weeds during harvesting of crops. Later the vector may move back into endive or other crop beds. Through the use of stained leafhoppers it was found that wind direction may play a large part in determining the direction of vector movement, and that such leafhoppers do not move in perceptible numbers much farther than 200 feet in four weeks.

The eradication of weeds within 100 feet of prospective lettuce and endive beds, by means of sodium chlorate crystals or spray, results in appreciable control of yellows at a cost of from \$33 to \$36 per acre of weeds.

Roguing yellowed lettuce plantings in small plantings was of little value as a control measure for the disease.

Dusting with either pyrethrum-sulfur dust containing at least 0.15 per cent pyrethrins, or with 1 per cent rotenone-sulfur dust, at weekly intervals from transplantation to harvest gave significant decreases of the yellows disease. An increase of only 5 per cent in marketable heads will normally pay for the cost of dusting.

Protection of young lettuce plants from viruliferous leafhoppers by growing them in cloth-covered coldframes or screened greenhouses prior to transplanting to the field resulted in a considerable reduction in the amount of yellows at harvest.

REFERENCES

- BECKWITH, C. S., AND HUTTON, SIDNEY B. Life history notes on some leafhoppers that occur on New Jersey cranberry bogs. New York Ent. Soc. Journ. **37**: 425-427. 1929.
- CAESAR, L., AND ROSS, W. A. Insects of the season 1932 in Ontario. Ontario Ent. Soc. Rept. **63**: 13-20. 1933.
- CARPENTER, C. W. The Rio Grande lettuce disease. Phytopath. **6**: 303-305. 1916.
- CLARKE, J. LYELL. New and significant experiences in mosquito control in the Desplaines Valley Mosquito Abatement district. New Jersey Mosquito Exterm. Assoc. Proc. **24**: 112-126. 1937.
- COONS, G. H. Diseases of field and vegetable crops in the United States in 1921. U. S. Plant Indus. Bur. Plant disease reporter, Sup. **22**: 409. 1922.
- DELONG, D. M., AND CALDWELL, J. S. Hibernation studies of the potato leafhopper (*Empoasca fabae* Harris) and related species of *Empoasca* occurring in Ohio. Journ. econ. ent. **28**: 442-444. 1935.
- HAMILTON, C. C. Spraying and dusting experiments for the control of leafhoppers infesting dahlias and asters. Journ. econ. ent. **25**: 304-311. 1932.
- HOLMES, FRANCIS O. Aster-yellows virus. In Handbook of phytopathogenic viruses, p. 2-5. 1939.
- JONES, L. R., AND RIKER, REGINA S. Wisconsin studies on aster diseases and their control. Wisconsin Agr. Exp. Sta. Res. bul. **111**: 1-39. 1931.
- KUNKEL, L. O. Insect transmission of aster yellows. (Abstract.) Phytopath. **14**: 54. 1924.
- Studies on aster yellows. Amer. journ. bot. **13**: 646-705. 1926.
- Wire-screen fences for the control of aster yellows. (Abstract.) Phytopath. **19**: 100. 1929.
- Studies on aster yellows in some new host plants. Boyce Thompson Inst. Contrib. **3**: 85-123. 1931.
- Effect of heat on ability of *Cicadula sexnotata* (Fall.) to transmit aster yellows. Amer. journ. bot. **24**: 316-327. 1937.
- LEACH, J. G. Further experiments on the cause of "purple-top wilt" of potatoes. (Abstract.) Phytopath. **29**: 14. 1939.
- MCMILLAN, H. G. Diseases of vegetable and field crops (other than cereals) in the United States in 1927. U. S. Plant Indus. Bur. Plant disease reporter, Sup. **61**: 296. 1928.
- OGILVIE, L. Aster yellows in Bermuda. A disease of many cultivated plants. Bul. Bermuda Dept. Agr. Vol. **6**⁵: 7-8. 1927.
- OSBORN, H. T. Life histories of leafhoppers of Maine. Maine Agr. Exp. Sta. Bul. **248**: 53-80. 1916.

- PEPPER, BAILEY B., AND HAENSELER, C. M. Pyrethrum and derris as a control for the six-spotted leafhopper, a vector of lettuce yellows. Journ. econ. ent. 32: 291-296. 1939.
- SEVERIN, HENRY H. P. Yellows disease of celery, lettuce and other plants, transmitted by *Cicadula sexnotata* (Fall.) Hilgardia 3: 543-571. 1929.
- Field observations on the beet leafhopper, *Eutettix tenellus*, in California. Hilgardia 7: 282-350. 1933.
- Experiments with the aster-yellows virus from several states. Hilgardia 8: 305-325. 1934a.
- Transmission of California aster and celery-yellows virus by three species of leafhopper. Hilgardia 8: 339-361. 1934b.
- SEVERIN, HENRY H. P., AND HAASIS, FRANK A. Transmission of California aster yellows to potato by *Cicadula divisa*. Hilgardia 8: 329-335. 1934.
- SMITH, KENNETH M. Aster yellows. In Recent advances in the study of plant viruses, p. 288. 1933.
- STEARNS, L. A., AND MACCREARY, D. Leafhopper migration across Delaware Bay. Journ. econ. ent. 31: 226-229. 1938.
- TILFORD, PAUL E. Aster yellows disease. In Ann. rept. 48 (1928-29). Ohio Agr. Exp. Sta. Bul. 446: 63. 1930.
- TUTT, J. W. The migration and dispersal of insects, 1-132. 1902.
- WEISS, F. Diseases of the China aster. Amer. florist 64¹⁹¹⁷: 269-270. Feb. 28, 1925.
- Research revives hope for asters. Florists' rev. 63¹⁶³⁵: 27-30. Mar. 28, 1929.
- WHITE, R. P. Diseases of China asters. New Jersey Agr. Exp. Sta. Circ. 232: 1-4. 1931.

